Improvement Programme for England's Natura 2000 Sites (IPENS) – Planning for the Future IPENS049

Site categorisation for nitrogen measures

Birklands and Bilhaugh Special Area of Conservation (SAC)
Culm Grassland (SAC)
Ingleborough Complex (SAC)
Mole Gap to Reigate Escarpment (SAC)
North York Moors (SAC)
Walton Moss (SAC)

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Foreword

The **Improvement Programme for England's Natura 2000 sites (IPENS)**, supported by European Union LIFE+ funding, is a new strategic approach to managing England's Natura 2000 sites. It is enabling Natural England, the Environment Agency, and other key partners to plan what, how, where and when they will target their efforts on Natura 2000 sites and areas surrounding them.

As part of the IPENS programme, we are identifying gaps in our knowledge and, where possible, addressing these through a range of evidence projects. The project findings are being used to help develop our Theme Plans and Site Improvement Plans. This report is one of the evidence project studies we commissioned.

Atmospheric nitrogen deposition is considered a key threat to Natura 2000 sites and to the reaching of biodiversity objectives. These threats result from emissions of ammonia (NH_3, mainly from agricultural sources) and nitrogen oxides (NOx, mainly from transport, industry, power generation and other combustion sources). Substantial efforts in UK and European policies over the last decades have reduced NOx emissions considerably, with more modest achievements in reducing NH3 emissions.

Given the high spatial variability of nitrogen deposition, in particular for NH_3, at a landscape scale, local targeting of deposition reduction measures close to protected sites is considered a cost-effective approach to reducing atmospheric nitrogen impacts on these sites. Options include both source-oriented technical measures and landscape oriented measures (e.g. tree belts for dispersion and recapture of emissions). Identifying the most relevant local sources of atmospheric nitrogen (N) and potential measures is a key first step in developing an action plan to address this issue for protected sites.

The aim of this project was to evaluate a draft framework for source allocation of atmospheric N pollution and to assess how a more detailed source attribution can contribute to better targeting of measures. The application of this more detailed approach to different types of case study sites under this project aims to give insight into the detail needed for appropriate targeting of measures.

The outcomes of this study will be used to inform the IPENS theme plan on atmospheric nitrogen and Natura 2000 and will be used to trial the development of Site Nitrogen Action Plans.

The key audience for this work is decision makers involved in the development of a pro-active approach to addressing atmospheric nitrogen impacts on protected sites.

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Summary

1. The **IPENS049 project** aimed to **evaluate a framework for source attribution of atmospheric nitrogen (N) pollution and targeting of mitigation measures**. The framework had two stages: an initial (coarse) scenario allocation, and a more detailed approach. Six Natura 2000 sites were selected as case studies to assess how a more detailed approach can contribute to better targeting of locally effective measures.
2. Following the application of this more detailed approach to the **case study sites**, a comparison with the initial (coarser) approach was carried out, to provide insight into the effort required to compile data for sites of different size/complexity and the value of more detailed data for targeting measures.
3. For all six study sites, the new/refined methodology allowed a **reliable distinction of the main threats** from atmospheric N to sensitive habitats and species, including whether each source type scenario (diffuse agriculture, point sources, roads, etc) allocated was due to substantial local sources, or largely due to long-range transport. This in turn allowed a relatively clear initial assessment whether **local mitigation measures** were likely to be worth considering for targeted reduction of atmospheric N at a site, or whether a **wider regional or national/international effort** would be the main route for improvements.
4. A new approach for **quantifying the importance of agricultural NH_3 sources** in the vicinity of a SAC was derived, by calculating non-disclosive local emission NH_3 emission densities and the likely contributions from the agricultural sectors for all SACs in England. This approach, combined with aerial image analysis and local information, allowed a much more detailed assessment of likely management practices associated with each sector and a more targeted selection of locally suitable mitigation measures.
5. While a reliable identification of the main threats and local vs. regional issues can be achieved with the approach described above, the **detailed selection of potential local measures** requires **local collaborations and sharing of information** on current management systems and practices, prior implementation of low-N systems and measures, etc. While this applies equally to all emission source sectors, it is particularly relevant for local agriculture, and work under the parallel project IPENS050 has shown the value of engaging with, e.g., local Catchment Sensitive Farming initiatives.
6. **Discussions with and input from local site managers** mostly confirmed the information derived by desk-based study for the six sites. However this input is crucial for developing detailed suitable and locally applicable sets of measures, as local management and systems information cannot be derived from other data sources, apart from some insight from recent aerial images such as Google Earth. In general, local engagement with all stakeholders including knowledge exchange on atmospheric N, its sources and effects on the SAC are deemed essential for constructive targeting of measures.
7. Overall, following testing of the detailed approach for six different sites, the following **key steps** are recommended, if the approach were to be extended to all SACs in England:
   a) **Analysis of N deposition (including source attribution, contributions from wet/dry deposition) and NH_3 and NO_x concentrations**, for all parts of geographically separated sites;
   b) **Analysis of relevant data for all relevant source attribution scenarios allocated to each SAC** (or component parts) – diffuse and point source agriculture, roads, non-agricultural sources, long-range N input;
   c) **Familiarisation with the site, aerial images and output from the previous analysis steps**, pulling together of **draft site profile and draft list of** potentially suitable **measures** for local targeting;
   d) **Communication with local site managers and other interested stakeholders** to check site profiles and preparation of a **revised list of suitable locally applicable measures**.
8. **Further work** recommended includes a **new up-to-date source attribution dataset** that also provides output separately for a larger number of forms (chemical species) of N. This would allow the distinction between, e.g., medium/long range ammonium (NH_4^+) deposition and short-range ammonia (NH_3) dry deposition. Further recommendations include **automated**

detailed approaches for the remaining scenarios for all SACs and **wind rose data for longer-term averages for all sites**.

9. If the approach developed under this project and the parallel IPENS-050 project were to be implemented to produce site profiles for all SACs in England, this would provide a comprehensive resource to engage with local stakeholders and raise awareness and understanding of the issues of atmospheric N input to sensitive habitats. Taking this a step further, a small number of pilot studies could test the implementation of measures, combined with atmospheric monitoring and modelling before/after implementation, to allow thorough quantification of the approach and its costs/benefits.

1. Introduction – project background, preceding work and aims of the IPENS049 project

Atmospheric nitrogen (N) deposition represents a significant threat to habitats and species in the UK. It leads to nutrient imbalances associated with eutrophication and acidification, resulting in declines in many of the key species of high conservation value at the expense of a smaller number of fast growing species that can exploit conditions of improved nitrogen supply (e.g., Dise *et al*. 2011, RoTAP 2012). These threats result from emissions of ammonia (NH_3, mainly from agricultural sources) and nitrogen oxides (NO_x, mainly from transport, industry, power generation and other combustion sources). Substantial efforts in UK and European policies over the last decades have reduced NO_x emissions considerably, whereas, so far, much less has been achieved in reducing NH_3 emissions. Many protected sites in the UK remain under substantial threat, with thresholds for atmospheric N pollution effects (Critical Loads for N deposition, Critical Levels for NH_3) exceeded across a large proportion the UK Natura 2000 network designated under the EU Habitats Directive.

Identification of the main sources contributing to N deposition at each site is the first step in targeting mitigation options, given the high spatial variability of NH_3 concentrations and dry deposition, in particular. These options include both source-oriented technical measures (e.g. covering slurry stores, catalytic converters for petrol engines) and landscape oriented measures (e.g. adapting local agricultural practice with low-emission buffer zones around sites, tree belts for dispersion and recapture of emissions, etc). A wide range of potential measures exists to reduce emissions from agricultural sources, however, in contrast to other countries, such as the Netherlands and Denmark, where legislation has been implemented to reduce emissions, there has only been limited uptake of NH_3 mitigation measures in the UK.

Previous work by the Centre for Ecology & Hydrology (CEH)explored the potential of spatially targeted measures to reduce N deposition to sensitive habitats. Following on from this, initial source attribution scenarios were allocated to each Natura 2000 site, and a draft framework for producing site action plans to identify key N threats for protected sites was developed, and a draft process for identifying the most appropriate abatement measures and potential delivery mechanisms to implement these.

The IPENS049 project aimed to evaluate the draft framework for source attribution of atmospheric N pollution and targeting of mitigation measures, for a selection of Natura 2000 sites and to assess how a more detailed source attribution can contribute to better targeting of measures. Following the application of this more detailed approach to the case study sites under this project, a comparison between the initial (coarser) scenario and the detailed approach aimed to provide insight into the value of using more detailed information for targeting of measures and the effort required to compile the information for sites of different sizes and complexity. This comparison aims to enable Natural England to decide on the level of detail required for assessing all Natura 2000 sites.

In summary, the project aims to:

- Apply detailed source attribution to six different Natura 2000 sites (each assigned to one of the five initial source attribution scenarios – diffuse agriculture, agricultural point sources, non-agricultural (point) sources, roads, long-range N input and a mixed site).
- Compare initial (coarser) scenario allocation with the more detailed source attribution approach developed under IPENS049.
- Provide recommendations on the value of targeting measures through detailed source attribution.

2. Methods

2.1. Brief description of initial scenario approach and its limitations

An initial (coarser) scenario allocation was carried out for all UK SACs and SSSIs as part of preceding work. This allocated each protected site to one or more N deposition scenarios, using a combination of the APIS source attribution dataset (2005) and the distance of the site boundaries to large intensive pig and poultry farms (falling under the Industrial Emissions Directive, IED) and major roads (data from the Department for Transport, DfT). See Table 1 for the method used.

Table 1: Definition of the five scenarios using the UK source attribution dataset for N deposition (translation from the source categories used in APIS)

Scenario ID	Scenario name	Sources of N included in Scenario assessment		Criteria for Scenario Assessment
		APIS categories	**Components of N deposition included**	
1	Lowland agriculture (many diffuse sources)	- Ammonia emissions from fertiliser use - Livestock production	Total N deposition (Wet and dry NO_x and NH_3)	Total N deposition from agricultural sources (livestock, fertiliser) > 20 % of total N deposition
2	Agricultural point source(s)	- Ammonia emissions from fertiliser use - Livestock production	Total N deposition (Wet and dry NO_x and NH_3)	Total N deposition from agricultural sources (livestock, fertiliser) > 20 % of total N deposition AND site is within 2 km of an IED intensive farm
3	Non-agricultural (point) source(s)	- International Shipping - Other transport (excl. road transport) - Power stations - Refineries - Combustion plants - Energy production and transformation - NH_3 from non-agricultural sources[1]	Total N deposition (Wet and dry NO_x and NH_3)	Total N deposition from included sources (column APIS categories) > 20 % of total N deposition
4	Roads	Road transport	Total N deposition (Wet and dry NO_x and NH_3)	Total N deposition from road transport > 10 % of total N deposition AND site is within 200 m of a major road (motorway, primary or A-road)
5	Remote (upland) sites affected by long-range N input	All APIS categories [2]	Total Wet N deposition (NO_x and NH_3)	Total wet deposition > 40 % of total N deposition (wet and dry)

[1] Sources include: pets, wild animals, sewage sludge, composting, household products (solvents), humans (breath, sweat, babies nappies), landfill.

[2] Scenario 5 includes additional APIS source categories that were excluded from Scenarios 1-4, i.e. imported emissions and residual background sources (e.g. off-shore installations, crematoria, accidental fires, incineration etc.).

It is recognised that a more detailed source attribution with the additional datasets can potentially be very useful for quantifying contributions from local sources to N pollution at each site. In particular, an assessment of high resolution agricultural and non-agricultural emission sources and atmospheric NH_3 concentration data (1 km grid) can provide more detailed insight. Other important information required would be an assessment of the relative spatial location of likely local sources with regard to a protected site (distance, prevailing winds). Aerial images (Google Earth) can be analysed in detail around the boundary of each site. To better understand the atmospheric nitrogen pollution issues at each site and the likely importance of local, regional and more distant sources, these images could be analysed in detail. .

In order to be able to be able to identify and prioritise potential measures for local targeting near protected sites, especially for agricultural measures, a further key piece of information is local knowledge of management systems and practices. Without this information, average UK agricultural practice and associated emissions have to be assumed in the assessment. However, if farmers are already implementing mitigation measures, this needs to be taken into account both for crediting such reductions in local emissions to the farmers and for understanding the relative importance of local emission sources and the potential for further complementary measures. For example, a number of slurry tanks near a protected site may already have been fitted with covers, as has been shown in a case study for the parallel project IPENS050 (Cerne and Sydling Downs SAC).

2.2. Short description of methods developed to refine the approach

A more detailed approach has been developed to analyse available data sources to inform a site based action plan. Figure 1 shows the steps of this draft framework. Stage 1 (step 1 and 2) relate to the allocation of initial (coarse) source attribution scenarios, which has been applied to all SACs and SSSIs as part of previous work. Stage 2 (step 3 and 4) and step 5 relates to the detailed source attribution, which was further developed and tested on six case study site as part of this IPENS049 project.

Six different Natura 2000 sites were selected to exemplify the detailed approach, one for each of the five initial scenarios (diffuse and point source agriculture, roads, other non-agricultural sources, long-range transport – See Table 1 above for a detailed description) and a mixed case.

The results of applying the detailed source attribution guidance and selection of measures were summarised in individual site ‘profiles’, which each include a summary of the sites characteristics, graphics of the source contributions and potentially suitable measures, and are presented in an easily accessible format. The individual case study sites were agreed with the NE project officer and project steering group at the start of the contract (with main scenarios identified under stage 1 in brackets):

- Walton Moss (diffuse agriculture)
- Culm Grasslands (diffuse agriculture and agricultural point sources)
- Birklands and Bilhaugh (non-agricultural (point) sources)
- Mole Gap to Reigate Escarpment (roads)
- Ingleborough Complex (remote (upland) sites affected by long-range N input)
- North York Moors (mixed categories)[1]

[1] N.B. Only one of the four main sub-sites was investigated in detail, due to the large size of the site, by agreement with the Steering Group.

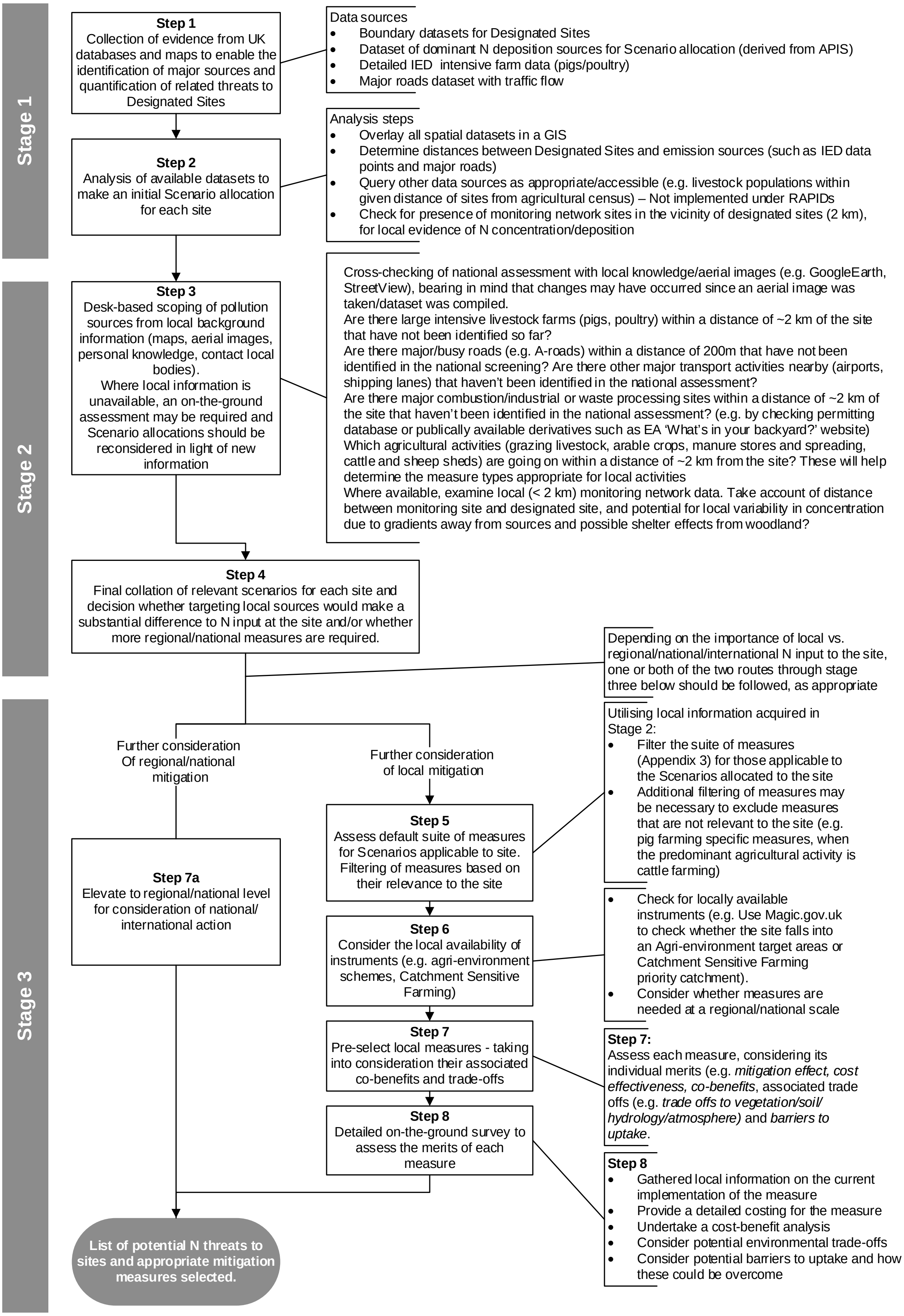

Figure 1: Summary of draft framework for establishing site action plans (developed by Ed Carnell, Ulli Dragosits, Mark Sutton (CEH Edinburgh) & Carly Stevens (University of Lancaster)

In summary, the following methodology improvements to the draft framework (Figure 1) were carried out under IPENS049 (see also Section 2.3 including Table 2, and Appendix 1 (spreadsheet) for more details on the data sources and related methodology):

- Where a site consists of multiple **geographically separate units**, individual component parts were considered separately, to allow a significant step forward compared with the analysis carried out for whole SACs/SSSIs only, rather than their constituent parts.
- Newly available **high resolution NH_3 concentration data** (1 km grid, see Table 2 and Appendix 1 for more details) were used in the detailed approach to identify areas with high NH_3 concentrations. The high spatial resolution of the data means that concentration hotspots can be identified, as well as NH_3 source areas (e.g. dominated by diffuse agriculture) be separated much more successfully from semi-natural NH_3 sink areas than at the 5 km grid resolution, thus allowing a more realistic quantification of NH_3 concentrations for SACs.
- The **National Ammonia Monitoring Network** (NAMN) dataset was also checked to identify monitoring sites present in the vicinity of a SAC. This allowed both a comparison with the modelled 1 km grid concentration dataset and a more detailed exploration of any temporal variation in concentrations (monthly measurements over several years).
- A major development of the refined approach under IPENS049 was a new methodology to identify the proportion of the **main agricultural sectors contributing to NH_3 emissions** in a local zone surrounding each SAC (2 km from the boundary) and to estimate an **average NH_3 emission density** for these zones using average UK emission factors produced by Misselbrook et al. (2013). This was possible due to Defra granting a project license to use agricultural census/survey data at a holding level. In order to comply with the data licensing agreement, emission estimates from each sector have been made non-disclosive, i.e. contain data relating to at least 5 agricultural holdings. In extensive agricultural regions, where this requirement was not met, the buffer zone around the site boundary was increased to include further agricultural holdings. This methodology was applied to all SACs in England, with a non-disclosive dataset produced for the project.
- More **detailed management data for large intensive pig and poultry farms** (permitted under IED) were made available by the EA, for input into the assessment of the six case studies, i.e. numbers and types of birds/pigs and housing/manure storage systems, in addition to the spatial location. These data were used as input to the **SCAIL screening tool**, to estimate the contribution of individual IED farms to N deposition and NH_3 concentrations at the sites. In addition, the spatial location of the site relative to the point source was taken into account in the preparation of the site profiles, including the **local prevailing wind conditions** to give a higher weighting to sources upwind of a designated site. Prevailing wind was determined using information from suitable nearby weather stations on Windfinder.com (where available).
- For **non-agricultural (point) sources**, more detailed searches through National Atmospheric Emission Inventory (NAEI) datasets and the detailed categories of the UK source attribution dataset were conducted, as the initial scenario allocation combines a multitude of different source types (e.g. industry, power generation, shipping, waste processing). Therefore to enable the identification of potential measures, the individual sub-categories of emission sources from both the source attribution dataset and emission maps from the NAEI were used allow a more detailed identification of sources. In particular, this was implemented under IPENS049 by searching for any significant point sources included in the non-agricultural **point emission datasets for NO_x and NH_3** from the NAEI within 10 km of a site.
- To improve the assessment of **major roads** as N sources near protected sites, NO_x emissions were calculated using the **Defra Emission Factor Toolkit & DfT traffic counts**, in addition to the N deposition threshold and simple distance-relationship between road/SAC used under the initial scenario approach. Under the initial scenario approach, **road transport** was assigned as a significant source of N deposition to a site where vehicular emissions contributed to > 10 % of the total N deposition in the relevant 5 km grid square, in combination with the presence of a major road within 200 m from the site

boundary. The more detailed methodology refines this approach by extracting annual average daily flows (AADF) of traffic (DfT, 2012) for each major road identified by the coarse approach and estimating NO_x emissions for each road link, using Defra's freely available Emission Factor Toolkit.

- For sites affected by atmospheric N sources located further afield (**long-range transport**, classified using wet N deposition as a proportion of the total N deposition under the initial scenario approach), more detailed data were extracted from the source attribution dataset to identify the contribution from different source types to the N input. This gave a better insight into the actual N sources, to allow more informed targeting of measures for wider surrounding areas or national/international policy recommendations. The most suitable measures for decreasing long-range deposition are likely to be needed at a regional, national or international level rather than at a local level.
- **Google Earth imagery** was used in conjunction with the national datasets, to identify any additional sources and provide further information on the sources already identified, including distance of sources from the site boundary, visual assessment of local conditions etc.

2.3. Data sources

The data sources used in the project include nitrogen emission, concentration, deposition and source attribution data, high-resolution agricultural statistics, road traffic data, emission factors and calculation tools from the UK inventories, and auxiliary data such as SAC boundary data, Ordnance Survey OpenData, Google Earth, wind roses etc. An overview of the datasets is shown in Table 2 below, with more detailed descriptions provided in Appendix 1 (spreadsheet), including detailed lists of sources and supporting documentation (inc. links), restrictions of use, issues and limitations. Key limitations include uncertainties and inaccuracies in point source locations, datasets being out of date (e.g. source attribution, aerial images) etc. These are discussed further in the results and discussion section below, with examples given.

Table 2: Summary of datasets used in the project, description of data and output created. N.B. A more detailed version of this table includes information on sources, restrictions of use, methodology applied and limitations, please see Appendix 1.

Dataset (date of version)	**Description**	**Source of data and supporting documentation**	**Output (what has been created)**
Source attribution dataset (2005)	Estimated N deposition contributions from 160 different point and area sources (as shown in APIS), produced for the year 2005, using the FRAME atmospheric transport model.	APIS	Depositional source attribution has been assessed and presented in tables and pie charts for each of the 6 site profiles. Where a site covers multiple grid squares, the new IPENS approach extracts data for each 5 km grid square (compared with the initial scenario approach, which only extracts data for a single 5 km grid square with the maximum deposition for the site).
N deposition data (2010-12 average)	Concentration Based Estimated Deposition (CBED) of nitrogen. Latest available data are for 2010-2012 (3-year average) 5 km grid of N deposition for the UK.	APIS	Mapped spatial distribution of N deposition.
NH_3 concentration data (1 km grid) (2011)	FRAME NH_3 concentration estimates at a 1 km grid resolution.	CEH data, created under Defra NFC (Critical Loads exceedance) contract	Mapped spatial distribution of N Concentration

Dataset (date of version)	Description	Source of data and supporting documentation	Output (what has been created)
Annual average daily flow (AADF, 2012)	Annual average daily flow (AADF) for every junction to junction link on the major road network. Produced by the Department for Transport (DfT).	DfT	Total estimated NO_x emissions are presented as maps using the Ordnance Survey Strategi road data.
Emission Factor Toolkit (EFT, 2012)	Defra's Emission Factor Toolkit (EFT) calculates annual NOx emission rates and provides an emission breakdown by vehicle type, requires AADF data as input.	Defra	Total estimated NOx emissions are presented as maps using the Ordnance Survey Strategi road data.
High-resolution Agricultural Census data for England (2012)	Holding level data on livestock numbers and crop/grass areas.	Defra; NH_3 estimates: Misselbrook *et al.* 2013 (UK agricultural emission inventory for 2012, Defra report).	Estimates of total agricultural emission density in close proximity to the site (< 2 km) and the main emission sources (> 5 % of total agricultural NH_3 emissions) are presented as pie charts for each site.
IED permit database (2012)	A database of large pig and poultry farms from the Environment Agency. Farms that are included in the database have either: > 40,000 places for poultry; > 2,000 places for production pigs (> 30 kg); or > 750 places or sows	Environment Agency	Discussion of potential impact of large intensive pig and poultry farms on SACs in the site profiles, and N deposition from farm unit calculated where necessary.
Emissions from NAEI 'large' point sources (2011)	Point data of known non-agricultural NOx and NH_3 emission sources at known locations.	Defra/NAEI (National Atmospheric Emission Inventory)	Individual sources are discussed in the site profiles, if they are deemed relevant to deposition at the site.
OS OpenData for road line features (Strategi, January 2014)	1:250 000 scale vector data of the UK's major roads[1]	Ordnance Survey	Mapped estimates of roadside NO_X emissions.
Google Earth Imagery (mostly 2010-12)	Aerial imagery dataset, available for most of the world.	Google Earth	Mapped point sources surrounding the site.
Wind roses (2013-14	Annual wind roses for recent 12-month periods from weather stations in Europe.	http://www.windfinder.com/	Wind rose integrated into site profile.
National NH_3 Monitoring Network (NAMN, 2012)	NH_3 monitoring data taken from passive and active samplers to validate modelled NH_3 concentrations.	Defra	Data superimposed onto concentration maps and discussed in site profiles.
SAC boundary data (2011)	GIS dataset of SAC boundaries.	JNCC	Presenting the spatial location of the site in maps such as deposition, concentration and point sources.

3. Results – Analysis of differences between initial (coarser) and more detailed approaches

3.1. Refining the approach for assessing NH_3 concentrations and N deposition

The more detailed approach **considers SACs with geographically separate units individually**, by utilising the complete UK 5 km source attribution dataset. This is a significant improvement to the initial scenario approach, which analysed SACs/SSSIs as a whole, rather than considering their constituent parts. This distinction between the approaches is especially important for sites such as Culm Grasslands, which are comprised of multiple, isolated parts that are separated by distances of up to 60 km. Similarly, larger more continuous sites, such as the North York Moors or the Pennines, are exposed to atmospheric nitrogen input from a wide range of nitrogen sources, some of which may only affect a limited area of the SAC. An example is shown in Figure 2, with individual source attribution pie charts for each of the constituent parts of Culm Grasslands, overlaid on a map of total N deposition at a 5 km grid scale. This shows clearly that sub-sites D and E are exposed to higher overall N deposition rates, with the source attribution broadly similar across the sub-sites. For this SAC in rural Devon, agricultural NH_3 deposition is the dominant source across the wider area, with sub-sites B, D and E being exposed to higher proportions of agricultural sources than the rest of the SAC. In addition to such considerations, certain mitigation measures may only be relevant to limited areas of a site, or a major source may only be close to one constituent part of an SAC, with no discernible effect on the remainder of the SAC.

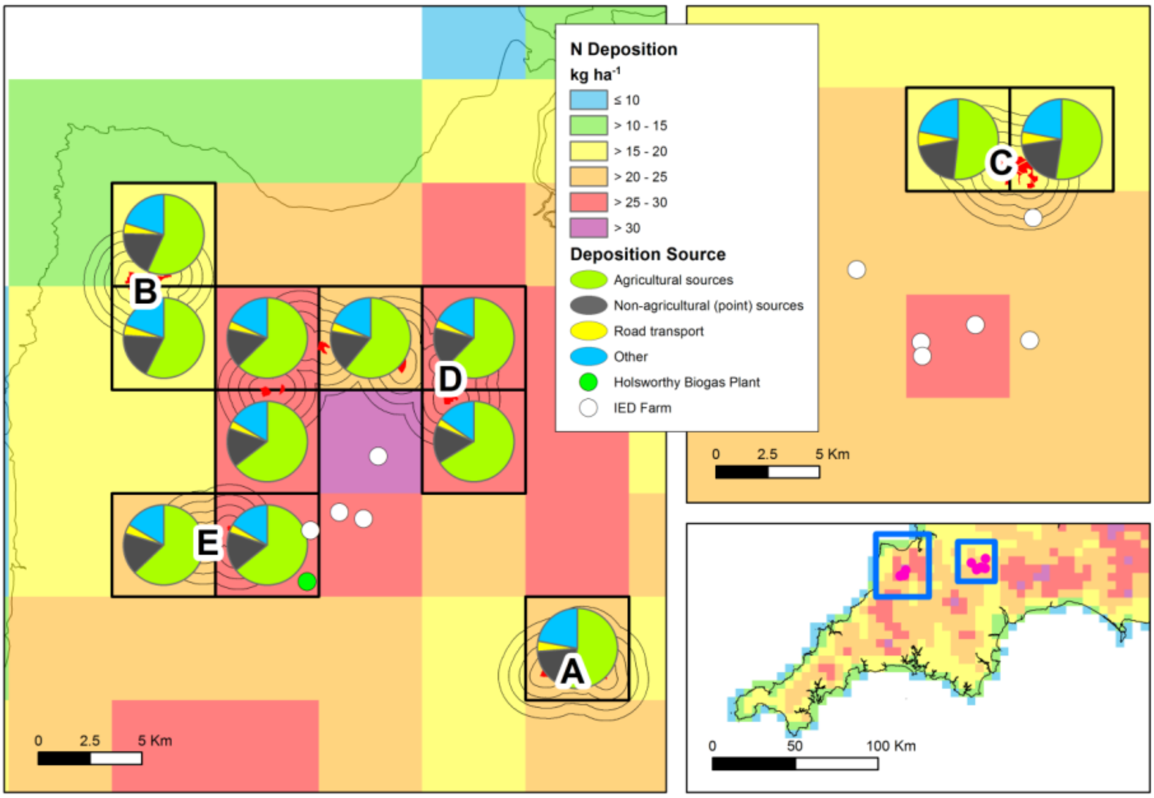

Figure 2: Estimated N deposition (2010 - 2012) and source attribution (2005) for Culm Grasslands SAC. 5 km grid squares that intersect the site are highlighted in bold. Sources are categorised using the scenario approach.

A further improvement to the initial scenario approach in the assessment of sites was the **new 1 km grid NH_3 concentration data** (FRAME model output, year 2011 –see Table 2 and Appendix 1 for more details), used in the detailed approach to identify areas with high NH_3 concentrations. The high spatial resolution of the data means that concentration hotspots could be identified, as well as NH_3 source areas (e.g. dominated diffuse agriculture) could be separated from semi-natural NH_3 sink areas much more successfully than at the 5 km grid resolution. Figure 3 clearly shows elevated NH_3 concentrations surrounding the intensive agricultural installations located to the south of sub-site D of Culm Grasslands.

By contrast, relatively low NH_3 concentrations of around or below 1 µg NH_3 m^{-3} at sites with relatively high N deposition are indicative of the N input being either mostly from **long-range transport** or predominantly from NO_x, as for large proportions of the Ingleborough Complex (Figure 4) and Mole Gap and Reigate Escarpment SACs (see site profile), respectively. This enables a clearer identification of sites where local measures are more likely to make a substantial difference to N input to a site, compared with those sites where local measures will at best enable very marginal improvements, if any. A coherent set of regional/ national/ international N reduction measures would be the only constructive way forward for such sites with very few local sources.

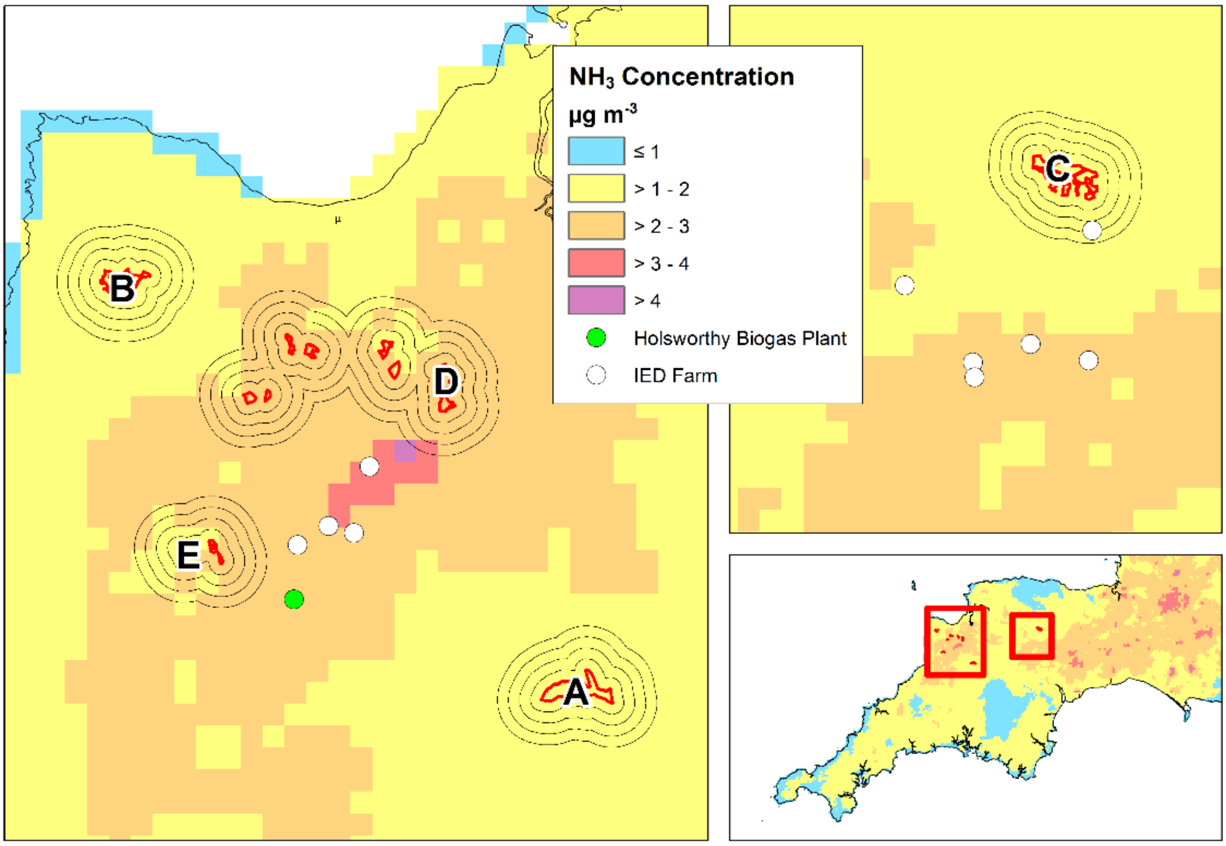

Figure 3: Ammonia concentrations at Culm Grasslands SAC (FRAME 1 km dataset for 2011), showing the location of IED farms and a biogas plant surrounding the site

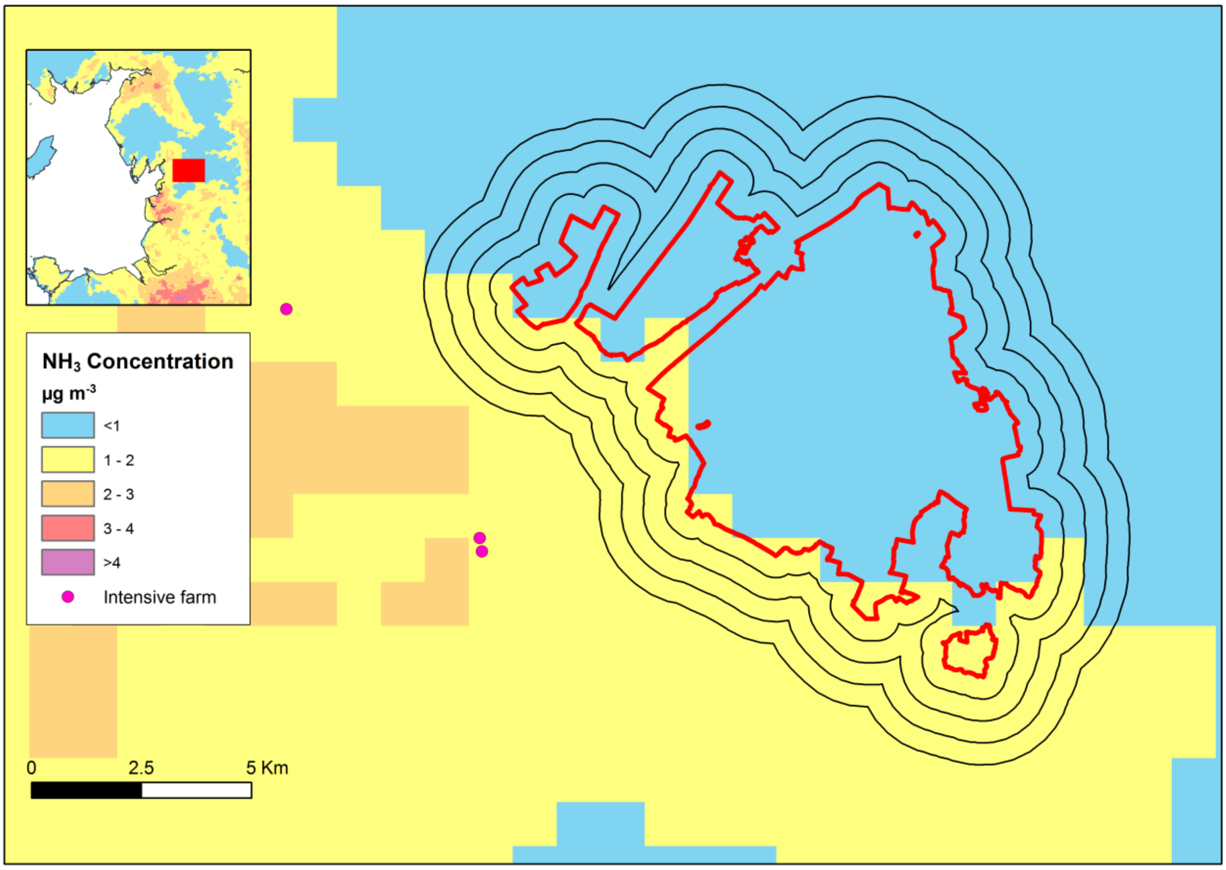

Figure 4: Ammonia concentrations at Ingleborough Complex (FRAME 1 km dataset for 2011), with the location of IED farms surrounding the site

There were very few **National Ammonia Monitoring Network** (NAMN) sites in close proximity to the six selected study sites. The closest sites found were two monitoring stations near the North York Moors SAC and one near Ingleborough Complex. As data from the sites run by NE (LTMN) were not available yet for analysis, only the NAMN site at Northallerton could be assessed. Even though located ~10 km east of North York Moors SAC, observed NH_3 concentrations were similar to those estimated by the model (Figure 5). The monitoring data also show monthly fluctuations in the NH_3 concentrations, which are thought to be indicative of manure/slurry spreading, with elevated concentrations coinciding with site operator notes mentioning a faint smell of manure at the NAMN site.

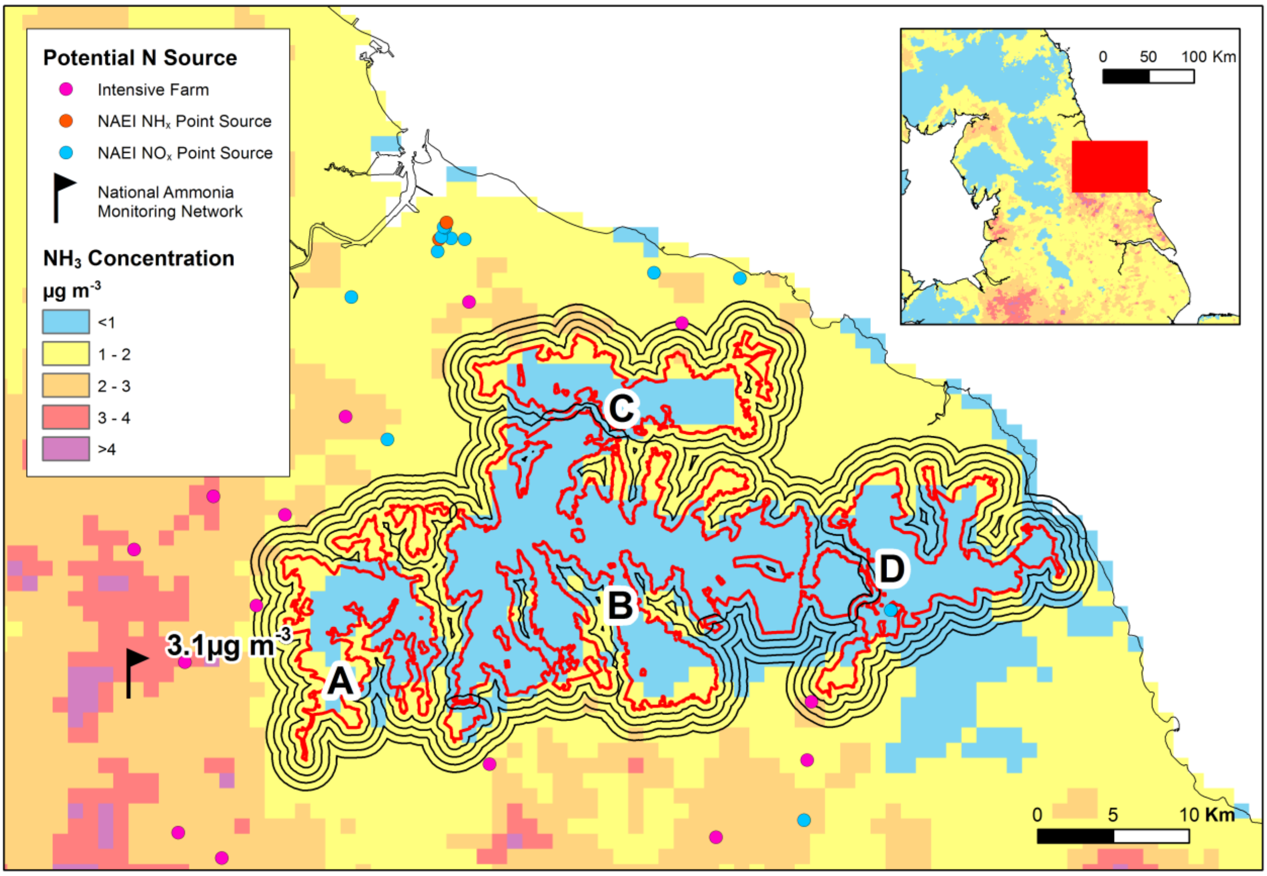

Figure 5: Ammonia concentrations at North York Moors (FRAME 1 km dataset for 2011), with the locations of N point sources surrounding the site. The observed concentration from Northallerton NAMN is also shown.

3.2. Refining the approach for assessing agricultural NH_3 emissions (diffuse and point sources)

The **agricultural census summaries** showed geographically separate areas of an SAC associated with different agricultural emission sources. The North York Moors SAC, for example, had marked differences in emission sources and densities, when comparing sub-sites A and C. Figure 6 illustrates this variation between agricultural emissions in the area (for further details see the site profile for the SAC). Poultry installations contribute substantially to sub-sites A and B, while sub-sites C and D have higher contributions from pig farming**.**

In this context, uncertainty over the exact location of holdings (e.g. post code points) and the associated fields under their management needs to be considered. For example, the real location of a holding's main livestock housing and manure storage activities, may be several 100m (in some rarer cases up to 1-2 km) away from where the holding is located in the agricultural census dataset, which may include/exclude the holding's activities from the assessment carried out for the 2-km zone surrounding an SAC. Similarly, the holdings' crop and grass fields may lie across the 2-km zone's boundary in varying proportions. However, given the overall relatively high density of holdings across large parts of England, the areas taken up by the 2-km zones around SAC and the local/regional distribution of different farm types, the data are expected to provide, on average, a good indication of overall emission density and representation of different agricultural sectors in an area.

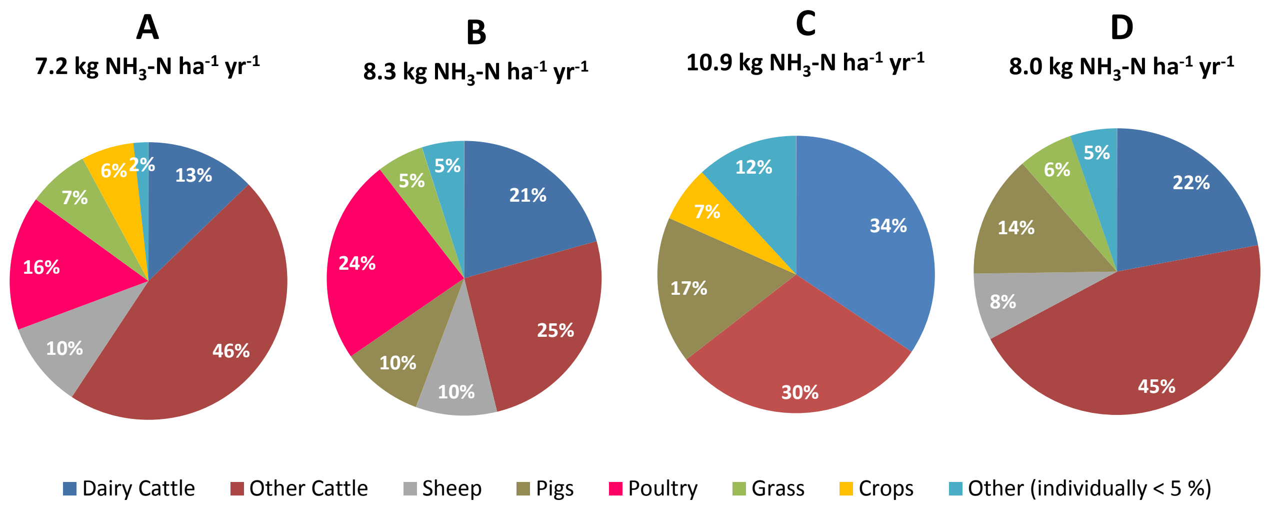

Figure 6: Agricultural NH_3 emission sources in the 2km zone surrounding the sub-sites of North York Moors derived from 2012 agricultural census and their corresponding emission densities

More detailed information on manure management and housing systems from the **EA database** for IED farms within a distance of 10 km to the 6 sites allowed modelling of the influence each installation had on total N deposition at the site, using the **SCAIL screening tool**. There were significant differences between the emissions produced by the IED farms tested, and it was not always the case that the closest installations to a site were the most substantial contributors to N deposition. The Bradworthy Common sub-site of Culm Grasslands SAC is a good example of this, as an intensive pig farm ~8.5 km from the site is estimated to contribute substantially more to total N deposition (~2.6 %) than a poultry installation ~5 km from the site (~0.2%). This is primarily due to the higher total emissions estimated for the pig farm, but may in part also be attributed to the modern manure management systems installed in the poultry unit (manure belt, removing manure twice a week). In addition, knowing which measures are already implemented (or in the process of being implemented) is critical for selecting applicable and locally suitable mitigation measures. In terms of uncertainty, one of the IED farm locations in the EA database was found to be several 10s of km away from the real location, with all other IED farms flagged as within 10 km distance from the six case study sites being located very precisely. If this process was automated across all SACs in England, further spot checks would be recommended, as false positives or false negatives could have a disproportionate influence on the identification of key local N sources. However, it is expected that such issues would be flagged by local site operators or other stakeholders.

3.3. Refining the approach for assessing non-agricultural N sources

Quantitative estimates of **road transport emissions from major roads** near the study sites were possible due to the availability of detailed traffic flow data (AADF), which were used in the freely available Defra Emission Factor Toolkit (EFT). Mole Gap to Reigate Escarpment SAC is a prime example of a site with major N issues from road transport, as it situated next to very busy sections of the M25, which passes the site at a distance of 50m from the boundary. The annual average daily traffic flow of this section of the M25 exceeds 140,000 vehicles daily (AADF, 2012) and is expected to produce 12 t NO_x-N km^{-1} yr^{-1}. By comparison, the A242 (situated >200m to the south of the site, Figure 7) has an AADF <7,500 and produces emissions of < 0.5 t NO_x-N km^{-1} yr^{-1}. It should be noted that the EFT calculations require input data on the average speed along the link. For this example, the national speed limit (70 mph) was used for the M25, however information from the local site manager (pers. comm.) indicated that this section is regularly badly congested, and therefore even higher emissions can be expected.

The assessment of the importance of **non-agricultural (point) sources** at the six study sites through the NAEI point dataset was straightforward, in that it involved a spatial data search for any significant NO_x or NH_3 point sources within 10 km of the site boundary. Only one of the case studies, Birklands and Bilhaugh SAC, had a point source as a significant local source at a distance of just under 10 km, a lime production plant emitting >1,000 t NO_x-N yr^{-1}. Further information on the plant and its operations were found online, including a planning application for fitting a pre-heater to one of the kilns, aiming to reduce emissions. Often, large point sources will contribute to long-range N input to protected sites, however other emission sources included in this broad category, such as shipping emissions, are likely to be relevant for a substantial number of coastal sites, especially in the south and east of England.

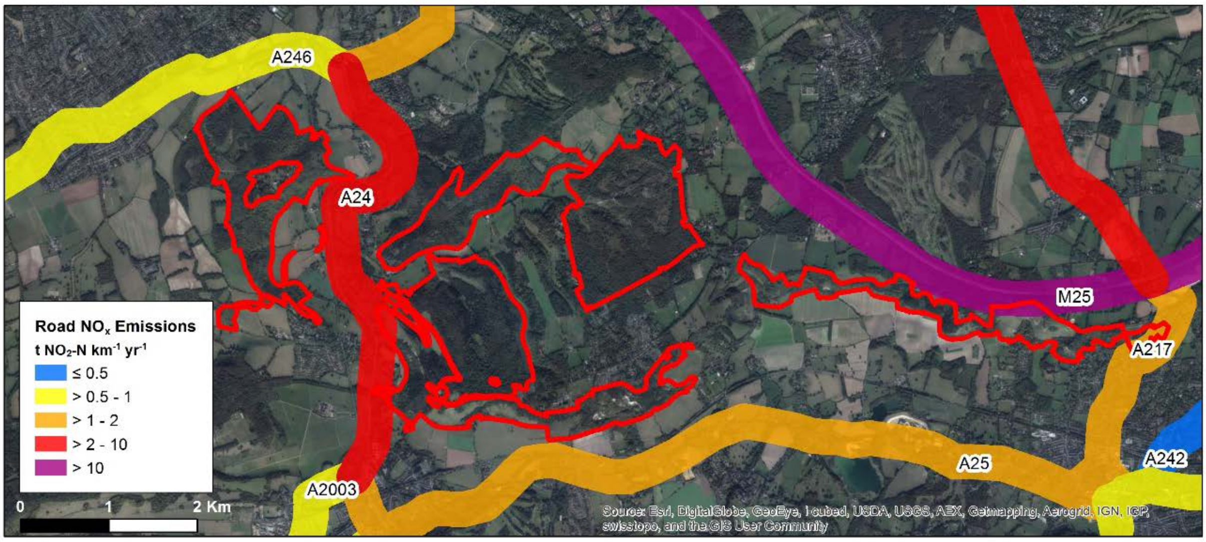

Figure 7: Estimated annual NO_x emissions (Defra EFT, 2014 and DfT AADF 2012) from road links surrounding Mole Gap to Reigate Escarpment SAC. Roads buffered to 200 m (following work by Cape et al. 2004).

3.4. Other improvements to the approach (aerial images, prevailing winds)

Google Earth imagery was used in conjunction with the analysis of national datasets, to spot any **additional sources and provide further information on the sources already identified**. An example of the types of information extract-able from aerial images is shown in Figure 8 for Walton Moss SAC, with features such as farm buildings, slurry stores and grazing livestock clearly identifiable. For some of the case studies, it was possible to identify local management systems. For example, some slurry stores were clearly visible with lids already fitted, i.e. evidence of measures having been adopted. However, there are significant issues with the images providing single snapshots in time and also being partly out of date (mostly 2010-2012 for the six study sites), and difficulties in assessing whether farm buildings/businesses are still actively used for agriculture, or whether they are mainly used as rural accommodation, with the surrounding fields sold off or rented out to neighbouring farms (see Section 4. for further details). The latter was a particular issue for one of the study sites of the parallel IPENS050 project (Cerne & Sydling Downs SAC), whereas the desk-based assessment of aerial images of Culm Grasslands, Mole Gap to Reigate Escarpment and Walton Moss SACs were mostly confirmed by local site managers during feedback discussions.

The **direction of the prevailing wind** was also factored into the detailed approach, to give a higher weighting to sources upwind of a designated site, compared with those downwind of designated sites and therefore, under average conditions, less likely to contribute to atmospheric N input at the site. Prevailing wind was determined using information from nearby weather stations on Windfinder.com, a free and easily accessible data source. Due to the website targeted at wind sports enthusiasts (surfers, sailors, sky diving etc.), there appears to be a bias towards coastal sites, and the average data provided freely are only available for a recent 12-month period (currently 2013-14). For one of the study sites, Ingleborough Complex, no suitable wind rose could be found, due to the hilly topography or coastal nature of the closest sites. In particular, it is more difficult to find representative wind roses for upland (topography/orography) and coastal areas (land-sea circulations). WindFinder is a quickly and easily accessible free data source, but longterm average wind roses would be more useful, to avoid extreme years giving a false impression of the average patterns. However, further improvements to this aspect of the methodology for assessing sites would require more time resources than were available under the project.

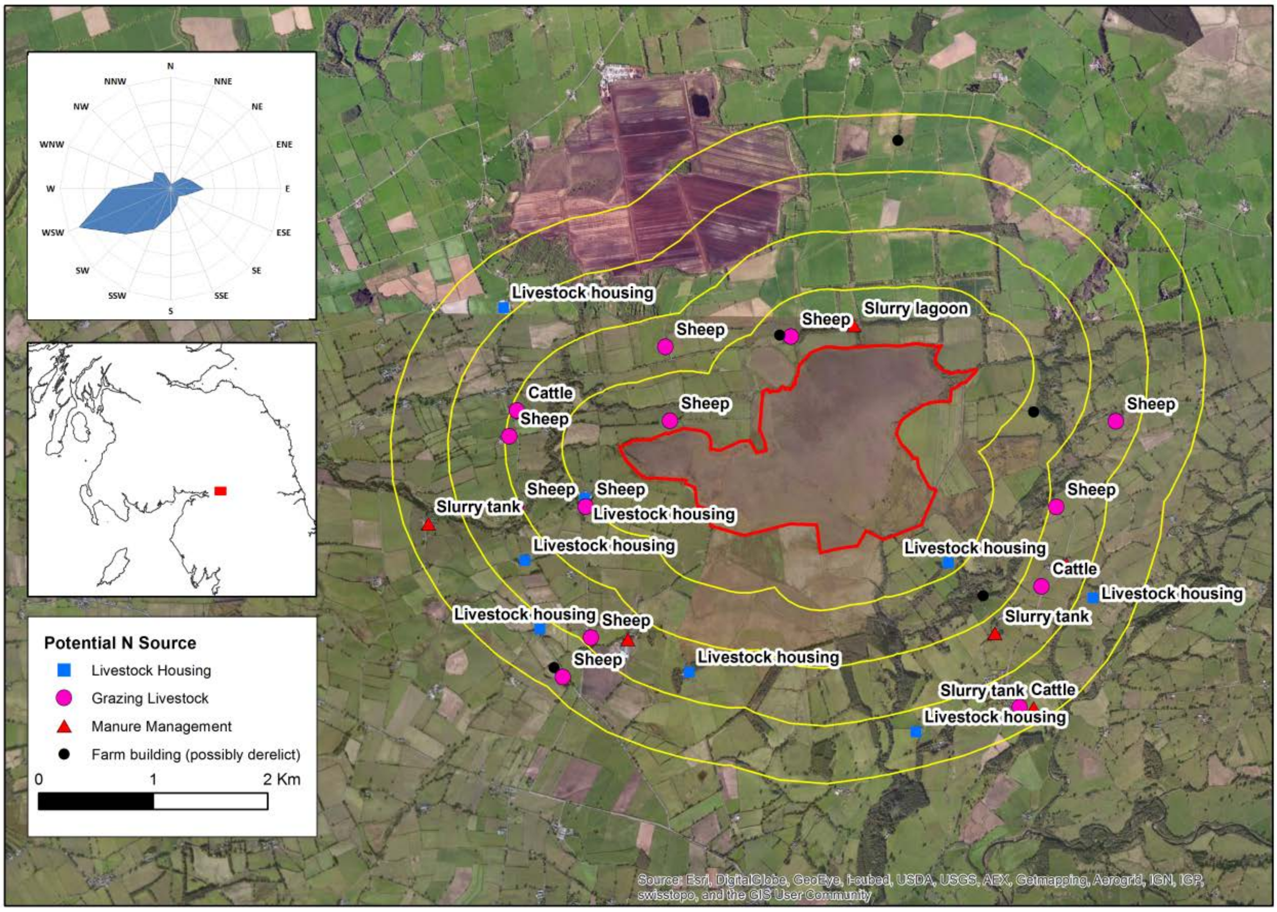

Figure 8: Walton Moss site map, showing N sources identified from Google Earth imagery, during a desk-based study carried out July 2014 (Google imagery date 30/05/2009). Wind rose shows the annual average (05/13 - 05/14) wind direction (%) in nearby Brampton (~5 km south of site), data from Windfinder.com (accessed 03/07/14).

3.5. Comparison of the coarser scenario approach and the refined approach

A **comparison between the initial scenario allocation and the refined methodology under IPENS049** is shown in Table 3 below. In this context, the initial scenario approach (shown as 'yes' and 'no' entries in Table 3) relied on a single site-wide table showing percentage contributions of the different scenarios to the total deposition, with each scenario colour-coded depending on whether a threat from atmospheric N was identified or not, with quantitative information on the distance to the nearest IED farm and major roads present in the vicinity. The refined approach includes a separate assessment of the separate constituent parts, where there are sufficient differences in N emissions, concentrations or deposition/ source attribution data, with additional data sources included in the assessment, as described in Sections 2 and 3 above. It is illustrated with colour coding in Table 3, e.g. 'initial allocation confirmed' in dark blue.

In general, the coarse scenario approach identified the main atmospheric N input sources for a site, but it was not possible to confirm whether a particular scenario was allocated to a site due to local sources in the vicinity, or whether the N threat was mainly due to medium/long-range transport of the N. For example, Mole Gap to Reigate Escarpment SAC is estimated to receive a substantial proportion of its N deposition to low-growing semi-natural features from diffuse agriculture, however, in the local scale assessment, very little agricultural activity was identified in the immediate vicinity of the site, and therefore local measures may not provide large reductions in atmospheric input to the SAC. This has also been confirmed by the relatively low atmospheric NH_3 concentrations across the SAC, which further confirm that local NH_3 sources are less likely to be an immediate threat to the site that can be remedied by local NH_3 measures.

Similar results were also found at Birklands and Bilhaugh SAC, with very few local NH_3 emission sources identified, despite only 26 % of the N deposition to the site estimated as wet deposition. This may be partly because of higher NO_x dry deposition from regional sources and further afield, as NO_x is much less reactive than NH_3. Ammonia dry-deposits rapidly near sources or is transformed to ammonium (NH_4^+) aerosol, which then is more likely to be wet-deposited at longer distances. Therefore, under the detailed approach medium/long range emission sources are more easily distinguished from local sources, and in the case of Birklands and Bilhaugh, identified as a potential threat to the site.

Furthermore, with the coarser scenario approach it was not possible to determine whether the whole site was affected by a particular scenario, or whether particular sub-sites were subject to different scenarios or levels of N input. For example, the more detailed approach confirmed, in combination with a parallel project carried out by Ricardo-AEA for NE (Claire Warburton, pers. comm.), that there may be an issue with N from roads at Birklands and Bilhaugh SAC. For this site, the initial scenario assessment was inconclusive, with roads flagged up as contributing 17% to N deposition above the threshold for assigning the scenario, but the nearest major road is situated beyond the 200m threshold, at 235m from the site boundary.

Table 3: Comparison between scenario allocations from the two approaches tested (initial scenario allocation and detailed source attribution methodology refined under IPENS049), separately for low-growing semi-natural designated features and woodland features (due to different deposition velocities). The initial scenario allocations are shown as 'yes'/'no' entries, with the refined IPENS approach shown in colour coding (e.g. 'initial allocation confirmed' in dark blue).

Initial Scenario Allocation / Case study site	Scenario 1 (diffuse agriculture)	Scenario 2 (point source agriculture)	Scenario 3 (non-agricultural (point) sources)	Scenario 4 (road transport) *	Scenario 5 (long-range transport)
	Semi-natural features				
Walton Moss	Yes	No	No	No	Yes
Culm Grasslands	Yes	Yes	No	No	No
Mole Gap to Reigate Escarpment	Yes	No	Yes	Yes	Yes
Ingleborough Complex	Yes	No	Yes	No	Yes
North York Moors†	Yes	Yes	Yes	No	Yes
	Woodland features				
Birklands and Bilhaugh	Yes	No	Yes	No	No
Mole Gap to Reigate Escarpment	No	No	Yes	Yes	No
Ingleborough Complex	Yes	No	Yes	No	Yes

† Comparison to detailed approach refers sub-site D only, as this was the only area to be assessed in detail under IPENS049.
***Roads: The roads scenario is only allocated if both tests (overall N deposition from roads> threshold, <200m distance between site boundary and major road) passed. Detailed information is shown in the site profiles for the six test study areas.**

Legend

Initial coarse allocation confirmed from local sources	Initial allocation confirmed but more likely due to regional/long-range issues	Potential threat not initially allocated under coarser scenario approach	No threat under either approach

Due to the simplicity of the initial scenario allocation derived from the 2005 source attribution dataset (5 categories only, see Table 1) there is a lack of any detailed information on the actual sources of atmospheric N input locally. Therefore using this simple allocation does not allow for any detailed selection of potential locally suitable measures. For example, local N sources for a site allocated to Scenario 1 (diffuse agriculture, many sources) could include dairy, beef, sheep and/or arable, as well as pig and poultry farming below IED thresholds. It would therefore not be possible to select measures at a level beyond those suitable for 'agriculture'. Once further detailed information is included, such as the non-disclosive dataset of local agricultural sectors contributing to NH_3 emissions, aerial images and/or local knowledge on management systems and practices, a detailed list of potential locally suitable measures can be compiled.

An important component of the site assessment was **input from local site managers**, both in terms of comments on the site profiles, which were derived through desk-based studies, and in terms of discussion of atmospheric nitrogen input as a potential issue at the sites. Written responses for four of the six sites were received (Walton Moss, Mole Gap to Reigate Escarpment, Ingleborough, Culm Grasslands), followed by telephone discussions in two cases (Walton Moss, Mole Gap to Reigate Escarpment). In general, the local information matched the desk based assessment very well, with much more detailed information available locally on management practices/systems, particularly in areas immediately surrounding the SACs. In Catchment Sensitive Farming (CSF) areas (Culm Grasslands, Walton Moss), relationships with farmers are either well established or in the process of being established. Similar to the experience of the parallel IPENS050 project, working in partnership with local groups (such as CSF) would provide a major benefit in the establishment of **detailed definitive lists of suitable local measures** for targeting in the vicinity of the SAC. However, it is also clear that substantial further benefits could be had from developing knowledge exchange with all local stakeholders, especially given the relative lack of awareness of atmospheric N issues, effects on sensitive habitats (and how they manifest themselves), compared with, e.g. water quality issues. In particular, there is **substantial interest in atmospheric N issues from local site managers**, and a **clear need for dissemination of information** on how to identify N effects and mitigation options.

3.6. Estimates of site-specific NH_3 emissions, potential mitigation and costs for two sample sites

Two SACs (Cerne & Sydling Downs[2] and Culm Grasslands (sub-sites D and E, see also draft site profile)) were selected to illustrate the differences between using national-level data (i.e. those used in the national emission inventory) and more detailed local information for calculating emissions from local sources. This was supplemented by estimating potential local emission reductions and associated costs of implementing the most efficient measures suitable for local systems, practices and environmental conditions.

Site-specific NH_3 emission estimates

For the Cerne & Sydling Downs and the Culm Grasslands (D and E sub-sites) sites, NH_3 emissions were estimated using site-specific management practice data provided by the Catchment Sensitive Farming Officers (CSFO) under the IPENS050 project (Appendix 2). These emission estimates were then compared with estimates made using UK average emission factors based on average management practice data. For Cerne & Sydling Downs, site-specific data were obtained for cattle and pig production, whereas for the Culm Grasslands sites the focus was on cattle, as they are by far the major livestock present. No site-specific information was available regarding fertiliser use for the sites, so the UK average emission factor (weighted across all fertiliser types and application practices) was used.

The site-specific farm practice data were used in the UK agricultural NH_3 emission inventory model (NARSES – version used for the 1990-2013 inventory submission) to derive site-specific emission factors per animal type and per hectare for fertiliser applications to crops. The national and site-specific emission factors, respectively, were then combined with high resolution data on livestock numbers and crop areas (for areas within 2 km of each site boundary) to derive total emission estimates for each site (Table 4).

Site-specific emission estimates were lower than those using UK average management practice data for all sites, but only marginally so for the Culm Grassland sub-sites. For Cerne & Sydling Downs SAC, emissions from dairy cattle were greater using site-specific practice data, despite the housing period being shorter than the UK average. This was mostly due to the large increase in the

[2] Culm & Sydling Downs SAC was selected for this illustration, as detailed agricultural management information was available from the complementary IPENS-050 project (Misselbrook et al. 2014).

proportion of slurry stored in lagoons, which is associated with a much higher emission factor than tank or weeping-wall storage. However, emissions from beef cattle were much lower, mostly due to the much shorter housing period, and this reduction in the emission estimate more than offset the increase in dairy cattle emissions. For the Culm Grasslands sub-sites, the shorter housing period (i.e. lower emissions) was offset by the much more limited opportunity for rapid incorporation of manures due to the predominantly grassland-based agriculture.

Table 4: Emission estimates for each site based on national average and site-specific management practice data

	Cerne & Sydling Downs	Culm Grassland D	Culm Grassland E
National average (t NH_3)	189.4	203.1	90.8
Site-specific (t NH_3)	170.5	196.9	89.5
Difference (%)	-12	-3	-1

Site-specific mitigation scenarios

Three mitigation scenarios were run for each site: 1) implementation of housing options – grooved floor system for dairy cattle, acid scrubbers for pig and poultry housing; 2) implementation of slurry storage and spreading options – rigid covers for slurry tanks, floating covers for slurry lagoons, trailing hose slurry application for Cerne & Sydling Downs (where shallow injection was deemed to be unsuitable) and shallow injection for Culm Grasslands sub-sites D and E; 3) combination of housing, storage and spreading measures. The scenario details are given in Appendix 3.

Emission reductions for each scenario and the estimated annualised cost of implementation are given in Table 5 (lifetime of livestock houses assumed 20 years, 10 years for slurry stores – if facilities last longer than these periods, which is very likely, annualised capital costs will be zero, but annual operating costs, e.g. for air scrubbers, may still apply). Cost estimates for the measures implemented were derived from a wide range of sources, based on UK average implementation scenarios. In practice, implementation costs can vary considerably depending on specific farm circumstances, so the costs presented here should be viewed as broadly indicative. Costs for implementing low emission spreading techniques are based on contractor costs, rather than individual farmer purchase of machinery.

For Cerne & Sydling Downs, the greatest emission reduction was achieved through implementation of housing measures, with the majority due to the implementation of acid scrubbers on pig and poultry housing, and little reduction (although considerable cost) for cattle housing measures. There was little additional mitigation through implementation of slurry storage and spreading measures, largely because there is already a high uptake of pig slurry measures in the area. For the Culm Grasslands sub-sites, implementation of the housing measures (mostly to cattle) was very costly with little emission reduction. Much greater mitigation potential was estimated for slurry storage and landspreading measures.

For all sites, emissions could be reduced by approximately one third by implementation of housing, slurry storage and slurry application measures. The housing and potentially slurry tank cover measures are not suitable for retro-fitting, so assume implementation at the time of house or store replacement. For the given sites, this will have implications on the timescale of implementation, or alternatively the magnitude of costs if implementation is to be brought in sooner than the natural replacement rate.

Table 5: Costs of implementation and emission reductions for the mitigation scenarios

Scenario	Total cost of implementation (£)	Total reduction in emission (kg NH_3)	% reduction within target area	Cost effectiveness (£ per kg NH_3 abated)
Cerne & Sydling Downs				
Housing	176,706	48,210	28	3.67
Storage and spreading	10,464	11,716	7	0.89
All	187,170	61,076	36	3.06
Culm Grassland D				
Housing	63,235	5,249	3	12.05
Storage and spreading	58,491	54,093	27	1.08
All	121,727	62,172	32	1.96
Culm Grassland E				
Housing	28,791	2,236	2	12.88
Storage and spreading	29,949	26,136	29	1.15
All	58,739	29,788	33	1.97

3.7. Estimate of resources required for extending the refined approach across England

Table 6 presents the **estimated times to conduct each task of the new/refined approach**. It should be noted that not all tasks are applicable to all SACs, e.g. the SCAIL screening tool was only used for sites with large intensive pig and poultry farms within 10 km extracted from the EA database for IED farms. Similarly, road traffic emissions were only quantified for sites with major roads in the vicinity. Some tasks have been automated, e.g. the calculation of non-disclosive agricultural emission densities and main agricultural source sectors for all SACs in England, and the data provided to NE as part of the contract (N.B. the database contains data for whole SACs only, with only the 6 case studies being analysed in more detail here.). There is scope to automate other tasks, such as calculating emissions from roads, however this would require more time resources than were available under the project, and a focus on agricultural data was agreed with the Steering Group. Furthermore, given the limited resources of the project, certain tasks were only carried out for one of the four sub-sites of the North York Moors SAC, due to the large size of the SAC (individual cells italicised in Table 3 where this applies).

Table 6: Estimated times taken for producing the information used in the site profiles for the six case studies, and factors influencing the time taken for the tasks carried out using the detailed approach presented here.

Process	Factors influencing processing time *method development not included here, agreed with the Steering Group*	Estimated time taken (minutes)					
		Walton Moss	**Culm Grasslands**	**Birklands and Bilhaugh**	**Mole Gap to Reigate Escarpment**	**Ingleborough Complex**	**North York Moors**
Extracting holding level data for areas surrounding all SACs in England from agricultural census and calculating non-disclosive summaries of agricultural NH_3 emissions	For all single-polygon sites (e.g. Walton Moss), agricultural census assessment ready. For SACs with sub-sites (e.g. Culm Grasslands), additional work was required to split those into sub-sites and re-process. This 2nd stage process could also be automated (or at least semi-automated) after agreeing on criteria and rules for splitting more complex sites.	0	30-60	0	0	0	30-60
Producing the source attribution table for each site, from UK source attribution dataset, which has been pre-processed to allow quick assembling and checking of values into tables	Depends on complexity of sites (number of sub-sites, area covered and how many different deposition types need to be considered)	10	25	10	15	10	25
Estimating NOx emissions from major roads surrounding the site	10 minutes to 1 hour (depending on number of transport links and junctions in the vicinity of each site)	0	15	35	60	0	*60†*
Identifying local emission sources (mostly agriculture) from Aerial Imagery (Google Earth)	Varies with density of emission sources, but can take > 2hours per site for larger sites or sites with several sub-sites	70	120	0	0	90	*90†*
Map production (Total N deposition and NH_3 concentrations)	Same timescale for each site (independent of size and complexity)	20	20	20	20	20	20
Identifying and researching non-agricultural point sources from the NAEI	Searching the database for emission sources in the vicinity of SACs is a straightforward and quick task (10 minutes), the process may take longer when it is necessary to do further research on the point source (e.g. checking progress on planning applications and reading site permits). The identification of nearby point sources could be automated for all sites, however checking the details against maps and sense-checking the information for each site is still recommended	10	10	40	10	10	*20†*
Assessing the probable origin of N deposition, for sites with high wet-deposition	Optional task, depending on whether there are substantial contributions of wet deposition and long-range measures that need to be considered	0	0	0	0	30	30
Total time (excluding method development and writing of site profile text)		**110**	**220-250**	**105**	**105**	**160**	**275-305**

† Please note, italicised values refer to a single sub-site of North York Moors SAC, conducting each task for the whole site is expected to take considerably more time.

4. Discussion & conclusions

1. In summary, the new/refined methodology derived from the initial draft framework and tested under the IPENS049 project allowed, for the six study sites, a **reliable distinction of the main threats**, including whether atmospheric N input from each source type (diffuse agriculture, point sources, roads, etc) allocated was due to substantial local sources, or whether it was largely due to long-range transport. This in turn allowed a relatively clear initial assessment whether **local mitigation measures** were likely to be worth considering for targeted reduction in threats from atmospheric N at a site, or whether a **wider regional or national/international effort** would be the main route for improvements.
2. A new approach for **quantifying the importance of agricultural NH_3 sources** in the vicinity of a SAC (here defined as a zone approx. 2 km from the site boundary[3]) was derived, by calculating a local emission NH_3 emission density and the likely contributions from the different agricultural sectors in a non-disclosive dataset for all SACs in England. This approach, combined with aerial image analysis and local information, allowed a much more detailed assessment of the likely management systems associated with the sectors present and a more targeted selection of measures most suitable for reducing the N input from these sources to the SAC.
3. While a reliable identification of the main threats and local vs. regional issues was achieved for the six case studies with the approach described above, the **detailed selection of potential local measures** requires **local collaborations and sharing of information** on current management systems and practices, prior implementation of low-N systems and measures, etc. While this applies equally to all emission source sectors, it is particularly relevant for local agriculture, and work under the parallel project IPENS050 has shown the value of engaging with, for example, local Catchment Sensitive Farming initiatives.
   For example, low emission landspreading techniques may already be used locally, which would need to be taken into account when the most effective draft package of measures is drawn up for a site. Without information on the local details, the refined methodology can only rely on average conditions across England as a whole, for estimating likely NH_3 emissions, using the national emission inventory methodology. Such detailed information can make a substantial difference in the final selection of measures suitable for targeting at a site, compared with relying on a remote desk-based study carried out with no local input.
4. **Discussions with and input from local site managers** mostly confirmed the information derived by desk-based study for the six site profiles. However this input is crucial for developing detailed suitable and locally applicable sets of measures, as local management and systems information cannot be derived from other data sources, apart from some insight from recent aerial images such as Google Earth. In general, local engagement with all stakeholders including knowledge exchange on atmospheric N, its sources and effects on the SAC are deemed essential for constructive targeting of measures.
5. As has been shown in the results, various **quirks and uncertainties** are present in the data used for the detailed approach, especially if there is a heavy reliance on **automated procedures** for some aspects of the assessment. However, it is anticipated that input from experienced members of the project team tasked with rolling out site profiles across the country, local site managers and other stakeholders is likely to prevent major errors or uncertainties from being present in the final site profiles.
6. Overall, following testing of the detailed approach for six different sites, the following **key steps** are recommended, if the approach were to be extended to all SACs in England:
   a) **Analysis of N deposition (including source attribution, contributions from wet/dry deposition) and NH_3 and NO_x concentrations**, separately for geographically separate parts of SACs, to determine main sources of atmospheric N input and whether the sources are likely to be of local or regional origin or from further afield – can be automated, but interpretation is required.

[3] Or a wider zone, up to 5 km, if there were insufficient numbers of holdings to satisfy the disclosivity rules.

b) **Analysis of relevant data for all relevant initial scenarios allocated to each SAC** (or component parts) – diffuse agriculture, agricultural point sources, roads, non-agricultural (point) sources, long-range N input. This step could be **further automated**, in a similar way as has already been done for diffuse agriculture under this project, especially for agricultural (IED database) and non-agricultural (NAEI database) point sources and roads (DfT data, or using output from recent Ricardo-AEA project carried out for NE).
c) **Familiarisation with the site, aerial images and output from the previous analysis steps**, pulling together of **draft site profile and draft list of** potentially suitable **measures** for local targeting (pending identification of local sources that could be effectively targeted to reduce N input to SACs) by staff with appropriate skills.
d) **Communication with local site managers and other interested stakeholders** to check site profiles and preparation of a **revised list of locally applicable measures** that could be targeted at a site.

7. In terms of **further work**, the following recommendations are listed in order of priority:
   a) a **new source attribution dataset**, with the current (2005) version being rather out of date, and consequently not containing a number of sources more recently included into the emission inventories (e.g. anaerobic digestion). Most importantly, a new source attribution dataset would allow better distinction of contributions from near/medium/long range sources, through more detailed output of N species from the modelling.
   b) **automated detailed approaches for each scenario for all SACs**, including the use of additional data sources, including all of the suggestions made in the tender documents for IPENS049 (for an England-wide detailed source attribution database). These suggested tasks were not possible in the given project time frame, and diffuse agricultural sources were identified as the main priority between the NE project officer and the contractors.
   c) **wind rose data for longer-term averages for all sites**, instead of the current quick and free images extracted from WindFinder for the 12 months. This could be automated using e.g. Met Office data, available, for example, through the British Atmospheric Data Centre (BADC).
8. If the approach developed under this project and the parallel IPENS050 project were to be implemented to produce site profiles for all SACs in England, standard methods (automated) and skilled interpretation of the data by the project team provide a comprehensive resource. This could be used to engage with local stakeholders and raise awareness and understanding of the issues of atmospheric N input to sensitive habitats. **Taking the implementation a step further towards applying targeted local measures to decrease N input to sites, studying a small number of sites would be recommended before wider implementation**. This pilot study should include the following key components, to allow thorough quantification of the approach and its benefits:
   a) comprehensive on-the ground stakeholder engagement, e.g. via existing CSF networks for agriculture (as per IPENS050).
   b) funding of measures e.g. through the proposed future NELMS and/or FFPS schemes.
   c) monitoring of atmospheric concentrations of NH_3 and/or NO_x and wet deposition (depending on the type of threat(s) identified) for suitable periods both before and after any implementation of measures.
   d) landscape-scale modelling of emissions, atmospheric concentration and deposition to quantify the effects of any measures, also taking account of regional N input and further afield (through inclusion of suitable boundary conditions for the local model domains).

Glossary of terms used in the site profiles

APIS – Air Pollution Information System (http://www.apis.ac.uk/) - APIS provides the UK national-scale source-attribution matrices at a 5 km grid resolution for assessment of N deposition and Site Relevant Critical Loads exceedance. Results are distinguished for designated features by type, for each SAC, SPA or A/SSSI in the UK.

Tree belts – Woodland belt planted downwind of an emission source or upwind of a site with sensitive habitats or species, to recapture N emissions and minimise atmospheric N deposition.

IED/Intensive farm – A large pig and poultry farm, which requires a permit from the Environment Agency. Farms. Qualifying farms are those which have: > 40,000 places for poultry, > 2,000 places for production pigs (> 30 kg); or > 750 places or sows.

NAEI point source – Point source data of known NO_x and NH_3 emission sources at known locations, available from the National Atmospheric Emission Inventory (NAEI) www.naei.org.uk.

Initial scenario definitions (Sc1, Sc2, Sc3 etc.) – see Table 1

References

Dise N.B., Ashmore M., Belyazid S., Bleeker A., Bobbink R., de Vries W., Erisman J.W. van den Berg L., Spranger T. & Stevens C. (2011) Nitrogen as a threat to European terrestrial biodiversity. Chapter 20, in: *The European Nitrogen Assessment* (Eds.: Sutton M.A., Howard C.M., Erisman J.W., Billen G., Bleeker A., Grennfelt P., van Grinsven H. & Grizzetti B.) pp. 463-494, Cambridge University Press.

Misselbrook T.H., Dragosits U. And Williams J. (2014) Case Studies for delivering ammonia measures. Final report to natural England on IPENS050. 16pp. URL: http://publications.naturalengland.org.uk/publication/5939668522631168?category=6337991412809728

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Appendix 1

Summary of datasets used in the project, including description of data, sources used, output created, restrictions of use, methodology applied and limitations.

Input Dataset	Description	Source of data and supporting documentation	Date of data used	Usage (how/what was done)	Output (what has been created)	Data restrictions of use	Issues/Limitations
Source attribution dataset	Estimated N deposition contributions from 160 different point and area sources (as shown in APIS), produced for the year 2005, using the FRAME atmospheric transport model.	**Data:** http://www.apis.ac.uk/srcl	2005	Each source has been categorised and allocated to initial scenarios, i.e. diffuse agriculture, point-source agriculture, roads, non-agricultural (point) sources, long-range transport. The contributions from each Scenario were then assessed to each Natura 2000 site and sub-sites of the chosen IPENS049 case-studies. This provides an initial indication of the potential threats from N deposition (5km grid resolution).	Depositional source attribution has been assessed and presented in tables and pie charts for each of the 6 site profiles. Where a site covers multiple grid squares, the new IPENS approach extracts data for each 5 km grid square (compared with the initial approach, which only extracts data for a single 5 km grid square with the maximum deposition for the site).	Freely available in APIS format	The dataset is nine years out of date. Components of Nitrogen have not been separated so it is hard to distinguish between local and regional sources.
N deposition data (from CBED)	Concentration Based Estimated Deposition (CBED) of nitrogen. Latest available data are for 2010-2012 (3-year average) 5 km grid of N deposition for the UK.	Data: http://www.apis.ac.uk/	2010-2012	Up to date estimates of N deposition, to complement the FRAME source attribution data derived for 2005.	Mapped spatial distribution of N deposition.	Freely available	N deposition varies at a much finer spatial scale than 5 km grid, depending on local sources and land cover (due to deposition-velocity), especially for NH_3.

Input Dataset	Description	Source of data and supporting documentation	Date of data used	Usage (how/what was done)	Output (what has been created)	Data restrictions of use	Issues/Limitations
NH_3 concentration data (1 km grid)	FRAME NH_3 concentration estimates at a 1 km grid resolution.	under Defra NFC (Critical Loads exceedance) contract; new dataset, derived for the 1st time for 2011, data series to be updated annually (see Defra project reports for detail).	2011	Extraction of spatial distribution of NH_3 concentration across the site and the surrounding area, to highlight the distribution of potential NH_3 emission sources.	Mapped spatial distribution of N Concentration	5 km grid data are freely available; 1 km data are a new development, these will be available to Defra and conservation agencies for internal use only (until potential disclosivity issues have been cleared with the authorities who provided some detailed input data).	1 km grid data are much more suitable for assessing the spatial variability of NH3 concentrations than the previous best resolution data (5km), however these data are derived from annual emission maps based on statistical distributions of emission sources and use average UK emission factors, rather than location-specific data, which do not exist.
AADF	Annual average daily flow (AADF) for every junction to junction link on the major road network. Produced by the Department for Transport (DfT).	**Data:** http://www.dft.gov.uk/traffic-counts/download.php **Metadata:** http://data.dft.gov.uk/gb-traffic-matrix/traffic-counts-metadata.pdf	2012	NO_x emissions estimated for every major road[1], which is nearby to the designated site (< 2 km), by inputting the AADF data into the EFT (defined as a separate record below).	Total estimated NO_x emissions are presented as maps using the Ordnance Survey Strategi road data.	Freely available	Time has to be spent finding correct AADF data for each road section and subsequently relating the road sections to the correct lines in the OS road data (Strategi). This is due to the DfT dataset not containing accurate spatial information (a simplified map is used by DfT, with straight lines connecting junctions)
EFT	Defra's Emission Factor Toolkit (EFT) calculates annual NOx emission rates and provides an emission breakdown by vehicle type, requires AADF data as input.	**Data:** http://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html **Metadata:** http://laqm.defra.gov.uk/documents/EFT-user-guide-v1.1.pdf	2012	NOx emissions estimated for every major road[1], which is nearby to the designated site (< 2 km), by inputting the AADF data into the EFT.	Total estimated NOx emissions are presented as maps using the Ordnance Survey Strategi road data.	Freely available	The EFT assumes an average speed for each road link. As the AADF does not contain this information, the national speed limit of each link has been used, which may produce some misleading results, especially on roads with high frequency of congestion.

Input Dataset	Description	Source of data and supporting documentation	Date of data used	Usage (how/what was done)	Output (what has been created)	Data restrictions of use	Issues/Limitations
High-resolution Agricultural Census data for England	Holding level data on livestock numbers and crop/grass areas.	**Data:** Defra **NH_3 estimates:** Misselbrook *et al.* 2013 (UK agricultural emission inventory for 2012, Defra report).	2012	NH_3 emission density and proportions of main agricultural NH_3 sources, estimated for 2 km buffer-zones surrounding each Natura 2000 site. The main NH_3 sources are then presented as a percentage of estimated NH_3 emissions from agriculture (ensuring that data from at least five holdings are used in the calculations, for disclosivity reasons).	Estimates of total agricultural emission density in close proximity to the site (< 2 km) and the main emission sources (> 5 % of total agricultural NH_3 emissions) are presented as pie charts for each site.	Access to raw data is restricted under a confidentiality agreement. Non-disclosive 2 km buffer zone summary data are made available to NE under IPENS049.	Uncertainty over farm location (e.g. assignment via post codes etc., with mapped locations very commonly not matching aerial images, in some cases by up to several km). The method applied treats any farm activities as linked to the location of the farm as a point rather than area source, in the absence of any other information on the farms' spatial extent. This leads to uncertainty of the livestock populations and crop/grass areas and related NH_3 emissions in buffer zones.
IED permit database	A database of large pig and poultry farms from the Environment Agency. Farms that are included in the database have either: > 40,000 places for poultry; > 2,000 places for production pigs (> 30 kg); or > 750 places or sows	Data: Environment Agency	updated regularly as part of permitting process	Extracted intensive farm data where farms are located < 10 km from a designated site. Livestock numbers were then used to estimate emissions and also to estimate the contribution of the farm to local NH_3 concentration and N deposition at the site using Simple Calculation of Atmospheric Impact Limits screening tool (SCAIL.ceh.ac.uk).	Discussion of potential impact of large intensive pig and poultry farms on SACs in the site profiles, and N deposition from farm unit calculated where necessary.	Some data are freely available via the EA website ('What's in your backyard?' - http://maps.environment-agency.gov.uk/wiyby/wiybyController), details from the EA.	The locations of some IED farms were inaccurate in the database (i.e. Inaccurately mapped).

Input Dataset	Description	Source of data and supporting documentation	Date of data used	Usage (how/what was done)	Output (what has been created)	Data restrictions of use	Issues/Limitations
Emissions from NAEI 'large' point sources	Point data of known non-agricultural NO_x and NH_3 emission sources at known locations.	**Data:** http://naei.defra.gov.uk/mapping/mapping_2011/NAEIPointsSources_2011.xlsx **Metadata:** http://naei.defra.gov.uk/data/map-large-source	2011	Point sources within 2 km of a designated site are extracted and their likely threat to the site is assessed based on factors such as their location with regard to the prevailing wind and distance to the site, in addition to the sources' estimated emissions.	Individual sources are discussed in the site profiles, if they are deemed relevant to deposition at the site.	Freely available	Some non-agricultural sources, such as landfill sites, are recorded as area sources (without a point location) and therefore have to be screened for manually under IPENS049.
OS OpenData for road line features (Strategi)	1:250 000 scale vector data of the UK's major roads[1]	**Data:** https://www.ordnancesurvey.co.uk/opendatadownload/products.html **Additional information:** http://www.ordnancesurvey.co.uk/business-and-government/products/strategi.html	01/2014	Improves spatial resolution of the AADT stylised road map, allowing distances between roads and SACs to be calculated more accurately.	Mapped estimates of roadside NO_X emissions.	Freely available.	The large scale of the data means that some links intersect sites, when in reality they pass within >5 m. Higher resolution OS data would provide more accurate results, if required.
Google Earth Imagery	Aerial imagery dataset, available for most of the world	**Data:** http://www.google.com/earth/download/ge/agree.html **Support:** https://support.google.com/earth/?hl=en#topic=4363013	Majority of images taken 2010-2012	Identification of likely emission sources surrounding the site.	Mapped point sources surrounding the site.	Freely available	Most of the imagery dates from 2010-2012, therefore sources which post-date the imagery will not be identified. Conversely, activities that may have ceased since the images were taken, are visible. Farm buildings, in particular, may no longer be actively used for farming activities - this was particularly prevalent for the Cerne & Sydling Downs SAC investigated in the sister project IPENS050.

Input Dataset	Description	Source of data and supporting documentation	Date of data used	Usage (how/what was done)	Output (what has been created)	Data restrictions of use	Issues/Limitations
Wind roses	Annual wind roses for recent 12-month periods from weather stations in Europe from WindFinder.com.	http://www.windfinder.com/	Typically 2013-2014	Estimation of prevailing wind direction, to determine whether emission sources are up or downwind of a designated site.	Wind rose integrated into site profile.	Freely available.	Some sites do not have weather stations nearby or at a suitable location to give a representative indication of wind direction (e.g. coastal sites vs., inland, areas with prominent topography); Annual snapshots are likely to be more variable than average wind data aggregated for a longer period, which would provide more reliable longer-term trends. Such data would either not be freely available or would require substantial pre-processing of freely available data.
National NH_3 Monitoring Network (NAMN)	NH_3 monitoring data taken from passive and active samplers to validate modelled NH_3 concentrations.	http://uk-air.defra.gov.uk/networks/network-info?view=nh3	2014	Monitoring data from NAMN and Natural England's LTMN sites within 2 km of a designated site are used to verify modelled concentrations (from FRAME).	Data superimposed onto concentration maps and discussed in site profiles.	Freely available.	Only one of the site-profiles had a NAMN site nearby. Data from LTMN sites are not yet available, as the data is still being processed.
SAC boundary data	GIS dataset of SAC boundaries.	JNCC	2011	Identification of sites, for extracting relevant information from spatial datasets on emission sources and relevant NH_3 concentration and N deposition data, etc.	Presenting the spatial location of the site in maps such as deposition, concentration and point sources.	Free for project use	The national scale SAC boundary map does not differentiate locations of designated features within site boundaries and features are therefore assumed to exist throughout the site for any assessment of effects of N deposition or NH_3 concentrations on habitats and species.

Appendix 2

Average national and site-specific management practice data.

Management practice	UK average	Site-specific	
		Cerne & Sydling	Culm D&E
Dairy cows kept on slurry (%)	83	85	80
Dairy followers kept on slurry (%)	35	85	80
Beef cattle kept on slurry (%)	18	15	10
Calves kept on slurry (%)	0	0	0
Dairy cows - housing period (d)	191	135	150
Dairy followers - housing period (d)	156	135	150
Beef cattle - housing period (d)	167	105	120
Calves - housing period (d)	165	105	120
Dry sows on slurry (%)	12	100	12
Dry sows on straw (%)	47	0	47
Dry sows outdoors (%)	41	0	41
% sows on reduced emission housing	12	0	12
Farrowing sows on slurry (%)	34	100	34
Farrowing sows on straw (%)	23	0	23
Farrowing sows outdoors (%)	43	0	43
Boars on slurry (%)	0	100	0
Boars on straw (%)	72	0	72
Boars outdoors (%)	28	0	28
Fatteners (20-110kg) on slurry (%)	34	100	34
Fatteners (20-110kg) on straw (%)	64	0	64
Fatteners (20-110kg) outside (%)	2	0	2
% reared pigs on reduced emission housing	18	0	18
Dairy slurry, % stored in:			
tanks	33	10	35
lagoons	33	90	60
% crusted	80	80	80
% covered	0	0	0
weeping wall stores	18	0	5
% spread direct	16	0	0
Beef slurry, % stored in:			
tanks	29	10	35
lagoons	29	90	60
% crusted	80	80	80
% covered	0	0	0
weeping wall stores	17	0	5
% spread direct	25	0	0
Pig slurry, % stored in:			
tanks	39	100	39
lagoons	34	0	34

% crusted/floating cover	18	0	18
% covered	18	100	18
% spread direct	27	0	27
% slurry applied to grassland:			
Dairy	76	76	90
Beef	88	88	90
Pig	46	46	50
Of slurry applied to arable, % incorporated within 6h:			
Dairy	6	6	6
Beef	6	6	6
Pig	6	6	6
Of slurry applied to arable, % incorporated within 24h:			
Dairy	19	19	19
Beef	19	19	19
Pig	19	19	19
% applied by trailing hose: **to grassland**			
Dairy	3	0	0
Beef	3	0	0
Pig	19	0	0
% applied by trailing shoe: **to grassland**			
Dairy	0	0	0
Beef	0	0	0
Pig	0	0	0
% applied by shallow injection: **to grassland**			
Dairy	1	0	5
Beef	1	0	0
Pig	11	80	0
% applied by trailing hose: **to arable**			
Dairy	3	0	0
Beef	3	0	0
Pig	15	0	0
% applied by trailing shoe: **to arable**			
Dairy	0	0	0
Beef	0	0	0
Pig	0	0	0
% applied by shallow injection: **to arable**			
Dairy	1	0	5
Beef	1	0	0
Pig	11	80	0
% FYM applied to grass:			
Dairy	60	60	80
Beef	60	60	80
Pig	22	22	50
Sheep	100	100	100

Layers	30	30	30
Other poultry	18	18	18
Of FYM applied to arable, % incorporated within 4h:			
Dairy	3	3	3
Beef	3	3	3
Pig	3	3	3
Layers	8	8	8
Other poultry	8	8	8
Of FYM applied to arable, % incorporated within 24h:			
Dairy	18	18	18
Beef	18	18	18
Pig	26	26	26
Layers	46	46	46
Other poultry	46	46	46

Appendix 3

Mitigation scenarios – Percentage of implementation of the different measures.

Mitigation measure	Cerne & Sydling Down				Culm Grasslands D and E			
	Baseline	Mitigation 1	Mitigation 2	Mitigation 3	Baseline	Mitigation 1	Mitigation 2	Mitigation 3
Dairy housing – grooved floor	0	100	0	100	0	100	0	100
Pig housing – acid scrubbers	0	100	0	100	0	100	0	100
Poultry housing – acid scrubbers	0	100	0	100	0	100	0	100
Cattle slurry tank – rigid cover	0	0	100	100	0	0	100	100
Cattle slurry lagoon – floating cover	0	0	100	100	0	0	100	100
Pig slurry tank – rigid cover	100	100	100	100	21	21	100	100
Pig slurry lagoon – floating cover	0	0	0	0	21	21	100	100
Cattle slurry – Shallow injection to grassland	0	0	0	0	5	5	100	100
Cattle slurry – Trailing shoe to grassland	0	0	100	100	0	0	0	0
Pig slurry – Shallow injection to grassland	80	80	80	80	0	0	100	100
Pig slurry – Trailing hose to grassland	0	0	20	20	0	0	0	0
Cattle slurry – trailing hose to arable	0	0	70	70	0	0	50	50
Pig slurry – trailing hose to arable	0	0	70	70	0	0	50	50